EFFICIENT IMPLEMENTATION OF LARGE SIZE FFT

Field of the Invention

This invention relates to Fast Fourier Transform (FFT) implementation and in particular to a system for efficiently implementing a FFT in a high data rate communication system.

Background

The ever increasing demand for high bandwidth services to homes and private enterprises has prompted ongoing investigations into methods of meeting these demands. It is well known that optical fiber links can propagate the required bandwidth for providing real time services such as voice and video. Progress in the installation of fiber to each and every home has been delayed due to the extreme costs associated with providing and connecting the necessary optical cables. For this reason efforts have been extended into finding ways of making use of the ubiquitous twisted copper pair which connects virtually every home to the Public Switch Telephone Network (PSTN).

Technologies such as Asynchronous Digital Subscriber Line (ADSL) have been successful in transferring signals in the low Mbps data rate over distances of a few thousand meters. There is, however, a need to deliver higher data rates for improved multimedia services and these needs can be met by a combination of optical cable and the twisted copper pair. Programs which introduce technologies like FTTN (fiber to the neighborhood) have meant that optical fibers are connected from a central office to one or more locations within a neighborhood or apartment building and the twisted copper pair is used to connect from this termination to the customer premises equipment. This reduces the transmission distance to a few hundred meters or more. It has been established that Very High Rate Digital Subscriber Line (VDSL) technology can transmit much higher data rates albeit over a shorter distance. At present data rates in the 13 mbps to 55 mbps can be achieved using VDSL technology.

VDSL technology typically uses discrete multi-tone (DMT) and Frequency Division Multiplexing (FDM) technologies. In such systems the available bandwidth is used to carry multiple channels of information and a Fast Fourier Transform (FFT) is typically used to convert frequency domain modulated signals into time domain

signals. In this technology a transmitter at the local Neighborhood Termination (NT) receives the data from the central office and converts it through an FFT function into a form for downloading on the twisted copper pair. At the receiver an Inverse Fast Fourier Transform (IFFT) function is used to obtain the original frequency signal. For large channel bandwidths with a large number of subchannels being used such as in the VDSL application, the FFT size, by necessity, is very large. This introduces two main drawbacks which make the DMT application in VDSL almost impractical. The first is that the FFT size is very large and this impacts from a chip design perspective and the second is that the execution of the function will take a long time. Accordingly, there is a requirement to develop a system for the efficient implementation of an FFT in DMT/FDM applications.

Summary of the Invention

It is an objection of the present invention to overcome the aforementioned problem by replacing one large size FFT with a few small sized FFTs. In this way, both computation time and chip size are reduced, especially for FDM applications, when only part of the frequency band is used for data transmission.

Therefore in accordance with a fist aspect of the present invention there is provided a system for implementing a Fast Fourier Transform (FFT) in a broad bandwidth, high data rate communications application, the system comprising: means to divide the bandwidth into subbands; and means to implement the FFT separately for each subband.

In accordance with a second aspect of the present invention there is provided a method of implementing a Fast Fourier Transform (FFT) in a broad bandwidth, high data rate communications application, the method comprising: dividing the bandwidth into sub-bands; and implementing the FFT separately for each sub-band.

Brief Description of the Drawings

The invention will now be described in greater detail with reference to the attached drawings wherein:

Figure 1 illustrates a typical transmit signal spectrum in an FDM system;

Figures 2(a) and 2(b) are block diagrams of a transmitter and receiver respectively according to the prior art;

Figure 3 shows a transmitter implementation according to the present invention;

Figure 4 shows a data receiver implementation of the present invention;

Figures 5(a) to 5(d) show the signal spectrum for a single subband at the transmitter of Figure 3;

Figure 6 shows the receiving spectrum of the same subband;

Figure 7 shows a second embodiment of a transmission system;

Figure 8 shows a second embodiment of a receiving system;

Figure 9 shows a signal spectrum of the embodiment of Figure 7; and

Figure 10 shows the signal spectrum of the embodiment of Figure 8.

Detailed Description of the Invention

In a typical DMT based system, an N point IFFT is used to transform N frequency subchannel carriers, with quadrative amplitude modulation (QAM) modulated data, into N point time domain samples. Figure 1 shows a typical transmit signal spectrum when frequency division multiplexing (FDM) is being used. The implementation is relatively simple: data is first modulated onto subchannel carriers using QAM modulation and the N point IFFT is applied. At the receiver end, FFT is applied first and then QAM demodulation is used to get the original data. The transmitter and receiver block diagrams are shown in Figure 2.

The problem with the above implementation is that both computation and chip size will be very large. In typical VDSL application, for example, N=8192. Also, since FDM is used in VDSL, only approximate half of the bandwidth is used for either down stream or up stream data transmission. Performing IFFT on the whole frequency band is a waste for both computation and clip size. In the following, a modification scheme is used where a couple of small size FFTs are used instead of one big FFT.

Figure 3 shows one implementation of data transmission according to one aspect of the invention, where the total frequency band (B) is divided into M sections each with bandwidth B_S=B/M and K of M subbands which contain non-zero signal are to be transmitted. In Figure 3, the signal is first modulated in individual bands and then an N/M point FFT is applied to each individual band to get the time domain signal. The time domain signal is further upsampled to the desired sampling rate and a bandpass filter is applied to put each subband signal into the right location in the total frequency band. The receiver shown in Figure 4 is the reverse operation of the transmitter shown in Figure 3. The signal is first filtered into individual bands and

then down sampled. N/M point FFT is applied to each subband signal and data is received with QAM demodulation.

Although in the above scheme, the same bandwidth is assumed for all subbands, variable bandwidth with variable FFT size and (up/down) sampling rates can be handled as well. As for the FFT size and filter selection, two different schemes can be used, as described next

Figure 5 shows the signal spectrum of the first scheme for a single subband of the transmitter of Figure 3. Figure 5(a) is the subband spectrum in the total frequency band which is to be transmitted. Figure 5(b) is the base band signal of the spectrum of Figure 5(a) where QAM modulation and IFFT are applied to the data being transmitted. Figure 5(c) is the upsampled spectrum of Figure 5(b) where the dashed line shows the filter with a proper frequency response to get the right signal spectrum in the total frequency band, which is again shown in Figure 5(d).

Figure 6 shows the receiving spectrum of the same subband. Figure 6(a) is the receiver signal spectrum together with the other subband signal. The dashed line shows the frequency response of the filter to get the proper single subband as shown in Figure 5(c). Figure 6(c) shows the down sampled signal spectrum, where FFT and QAM demodulation are applied to the base band signal in the period $[-\pi, \pi]$ to get the receive data.

The advantage of the first scheme is that the filters and the time domain signal are real with a symmetric spectrum. This means that only real signals will be obtained after the IFFT operation in the transmitter and all filter coefficients are real. A disadvantage of the scheme is that the signal subband must be located in the bandwidth $[k*(B/M), (k+1)*(B/M)]$, where B is the maximum frequency in the total frequency band and $k=0, 1, \ldots, M-1$.

The second scheme is discussed next where signals can be located in any frequency band $[F_1, F_2]$. In this second scheme, FFT is applied to only single side band spectrum and the other half can be recovered using the symmetrical property. Figure 7 and Figure 8 show the transmitter and receiver structures which are very similar to the architecture of Figure 3 and Figure 4. The main difference between the schemes is that down/up sampling by M is replaced with down/up sampling by 2M. Also since we are dealing with single band signal, the filter used is a single band complex filter and the size of FFT is a N/(2M).

Figure 9 shows the signal spectrum of the second scheme for the single subband of Figure 7. In this scheme the signal is located in any frequency band [F_1, F_2]. Figure 9(a) is the subband spectrum which is to be transmitted in the total frequency band. Figure 9(b) is single band signal of Figure 9(a) and Figure 9(c) is its down sampled version. Starting with the base band of Figure 9(c), which is again shown in Figure 9(d) QAM modulation and IFFT are applied to data based on the spectrum requirement of Figure. 9(d). Figure 9(e) is the up sampled spectrum and the dashed lines shows the filter with the proper frequency response to get the right single band signal spectrum of the total frequency band, which is again shown in Figure 9(f). It is to be noted that the signal spectrum is no longer symmetrical and as a result, both the time domain signal and filter are complex numbers. By taking the real part of the filter output, the symmetrical spectrum of Figure 9(a) is obtained. Since only the real part of the filter output is transmitted, the computation requirement for the complex filter operation is halved. Also, since FFT is only applied to the single band spectrum, the size of the FFT is half of that in Figure 5.

Figure 10 shows the receiving spectrum of the same subband. Figure 10(a) is the receiver signal spectrum together with the other subband signal. The dashed line shows the frequency response of the filter to get the proper single subband signal as shown in Figure 10(b). Again, since the input signal is real with a symmetrical spectrum and the single band filter is complex, the computation requirement for the complex filter operation is halved. Figure 10(c) shows the down sampled signal spectrum,where FFT and QAM demodulation are applied to the based band signal in the period [$-\pi$, π] to get the receive data. The spectrum in one period [$-\pi$, π] is also shown in Figure 10(d).

The advantages of scheme 2 are that the signal can be located in any frequency band [F_1, F_2], and the size of FFT is half of that in scheme 1 for the same number of subbands. It is especially suitable for FDM application where only part of the total channel is used for signal transmission. In such case, it is only necessary to process the bands whose time domain signal is non zeros. The only disadvantage is that the complex filter operation is required for both transmitter and receiver. However, as shown before, only half of the complex computation is required, which is only double (instead of four times) the computation of the real filter operation.

While particular embodiments of the invention have been discussed and illustrated it will be apparent to one skilled in the art that numerous alternatives can be introduced without departing from the basic concept. It is to be understood, however, that to the extent possible, such alternatives will fall within the full scope of the invention as defined by the appended claims.